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Influences of technological and sectoral contexts on technological innovation systems

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ABSTRACT

This paper analyses how technological and sectoral context structures influence the functional pattern of a focal technological innovation system (TIS), focusing on value chain interdependencies. Through a case study of the 'embryonic' bio-succinate from mixed food waste TIS in Sweden, we show that all identified context structures exert both negative and positive influences on TIS functions by influencing resource availability and accessibility, market conditions and the wider selection environment. Contextual influences result from interdependencies throughout the value chain, but in contrast to previous studies, direct structural overlaps are not as relevant as competition for resources, markets and policy support. Competition does not only come from the regime but also from other related TISs and sectors. The study also confirms the importance of contextual influences from the international TIS. These findings suggest that a wide perspective on context structures and selection pressures should be considered in future research.

1. Introduction

In recent studies of sustainability transitions, the technological innovation system (TIS) framework is one of two dominant perspectives (Markard and Truffer, 2008). Since its inception in the early 1990s (Carlsson and Stankiewicz, 1991) and the introduction and further development of the so-called functions approach in the late 1990s and early 2000s (Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004; Johnson and Jacobsson, 2001), the TIS framework has reached a widespread diffusion, especially among researchers interested in renewable energy and sustainable transitions.

In spite of its popularity the TIS framework has been criticized for being inward oriented and not paying enough attention to dynamics outside of the focal system (cf. Markard and Truffer, 2008; Smith and Raven, 2012). This is to some extent a misunderstanding; the functions approach has always acknowledged external influences on functions (Markard et al., 2015) and was originally developed to allow for the integration of influences from regional, national and sectoral innovation systems (Johnson and Jacobsson, 2001). Nevertheless, many analyses focus on processes that take place within individual TISs (Bergek, 2012) and our knowledge about how various "context structures" influence TIS functions therefore remains limited (Markard et al., 2015). More work on, for example, TIS–TIS interaction and the consequences of multi-sector couplings is, thus, needed (Bergek et al., 2015).

To contribute to this topical line of research, this article analyses contextual influences on the 'embryonic' TIS for the development of bio-succinate from mixed food waste (MFW) in the period of 2013—2017. In this period, this TIS only existed as a loose network of

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actors, resident in several established sectors (e.g. waste management and fossil chemicals). It was related up- and downstream to several other TISs (e.g. biogas, crop- and cellulose-based bioethanol and agro-based succinate) within and outside the geographical boundaries of Sweden. The purpose of this analysis is to demonstrate how different technological and sectoral context structures influence the functional pattern of a focal TIS in an embryonic phase of development, with a particular focus on value chain interdependencies.

In previous research, it has been suggested that external influences are extra strong in early phases of TIS development (Bergek et al., 2008c) and we therefore propose that an extreme case such as this will provide interesting general insights. The main contribution of the paper is, thus, to improve our understanding of the nature and effect of contextual influences.

2. Theoretical framework

2.1. Technological innovation systems and their functions

System perspectives on innovation emphasize that the development and diffusion of new technologies is a collective and interactive process, which is conditioned by institutional factors. The specific concept of 'technological (innovation) system' was introduced and defined by Carlsson and Stankiewicz (1991, p. 94) as "a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or a set of infrastructures and involved in the generation, diffusion and utilization of technology".

TISs are most often defined in terms of a product class or a field of technical knowledge (Bergek et al., 2008b). They are focused on novelty generation and should, therefore, be defined in terms of problem-solving networks rather than buyer-supplier relationships (Carlsson et al., 2002). Consequently, TIS actors are not only found in the supply chain of an industry but can also include, for example, universities, financial actors and policy making organizations. TIS analyses are often delineated to a specific country or region. Defining and delineating a TIS in technological and geographical terms implies that some actors, networks and institutions are considered to be part of the TIS, whereas everything else is considered part of the system's context (see Section 2.2).

While the structural elements is the starting point of a TIS analysis, much of the literature focuses on innovation functions. Functions describe what is achieved in the system in terms of a number of key processes that have a direct impact on the development and diffusion of new technologies, products and processes (Bergek et al., 2008b).[1] In other words, they are sub-processes to the overall innovation process and determine the innovation performance of the system (Bergek et al., 2008a). The functions are best described as emergent properties, i.e. they are the outcome of a complex interplay between actor actions and interactions, institutional influences, and self-reinforcing mechanisms, which unfolds over time (Bergek et al., 2008a, 2008b; Jacobsson, 2008).

In this article, we will use an adaptation of the framework provided by Bergek et al. (2008b), which covers a set of relatively broadly defined processes (Bergek, 2019, cf. 2012). The seven functions are described in Table 1 together with some examples of associated sub-processes.

It has been argued that the importance of specific functions or sets of functions might change over the lifecycle of a TIS (Markard, 2020). However, a core assumption of the framework is that all functions matter for system performance, regardless of the phase of development (cf. Bergek and Jacobsson, 2003; Johnson and Jacobsson, 2001). That most empirical studies include all functions seems to confirm this assumption. However, the function 'development of positive externalities' seldom becomes visible in very early phases of development, as it requires a critical mass of actors and systemic interactions to be present (Bergek et al., 2008b).

2.2. TIS in technological and sectoral context

Functions are not only influenced by the focal TIS, but also by system-external actors, networks and institutions at various levels of analysis (Jacobsson and Bergek, 2011; Johnson and Jacobsson, 2001). Such external influences are especially large in a formative phase, when the TIS structure is still weak and fragmented (Bergek et al., 2008b; Markard, 2020).

Fig. 1 summarizes the perspective on TIS in context applied in this paper, which highlights two dimensions, which are discussed in more detail below. First, it describes a focal TIS as being influenced by different *types of contexts*, focusing on related TISs (including the international TIS) and sectors. Second, it identifies different *types of influences*: whether they are positive (green arrows) or negative (red arrows) and whether they are due to up- or downstream interdependencies (blue sub-parts of the focal TIS). Whereas two-way interaction is possible, this paper focuses on one-way influences from context structures to the focal TIS since it is unlikely that an embryonic TIS would be able to exert much influence on its context.

2.2.1. Types of contexts

Previous research has identified several different types of context structures that can influence the development and functionality of a focal TIS. In this paper, we focus mainly on technological and sectoral contexts.

The *technological (innovation) context* can be conceptualized as a number of other TISs that are related to the focal TIS. Vertically related TISs are part of the same value chain as the focal TIS and horizontally related TISs refer to complementary or competing

[1] In contrast to some TIS literature, we do not define functions as structure-building processes (see e.g., Sandén and Hillman, 2011; Suurs and Hekkert, 2009). Instead, we respect the original intention of the functions framework to distinguish between structural and functional dynamics (cf., e.g., Bergek et al., 2008b; Jacobsson and Bergek, 2011, 2004), while still acknowledging that there can be feedback from functions to structure in emerging systems.

technologies (Bergek et al., 2015). The border between the focal TIS and context TISs is to some extent a matter of system delineation. Technologies can be defined more or less broadly, both in terms of alternative ways of developing and producing a focal technology and the number of applications and markets that are considered (Sandén and Hillman, 2011). A broad definition would result in a more complex focal TIS and fewer context TISs than a narrow definition.[2] Similarly, with a broad geographical definition more innovation dynamics would be seen as internal to the TIS, whereas a more narrow delineation would result in a wider set of context structures in the form of TIS located elsewhere. In this paper, the focal TIS is nationally delineated, which implies that the international TIS is considered a context structure (cf., e.g., Binz and Truffer, 2017; Dewald and Fromhold-Eisebith, 2015).[3]

The sectoral (production and consumption) context consists of the systems of production, distribution and use that are related to the focal TIS (Bergek et al., 2015). Such sectors do not only include the industries in which the innovations developed by the focal TIS will be produced and made available to the market but also – or even primarily – the industries or segments in which they will be implemented and used. In the sociotechnical transitions literature, this context is usually described in terms of an established sociotechnical configuration or 'regime' (Geels, 2004; Kemp et al., 1998; Smith and Raven, 2012). A focal TIS can be part of one or more sectors and sectoral affiliations can also change over time (Bergek et al., 2015; Markard et al., 2016).

In addition to these two contexts, the importance of the geographical context should be highlighted.[4] All TISs are embedded in different kinds of territorial contexts, for example specific regions or countries. The functionality of a focal TIS can, therefore, be influenced by general 'local' characteristics, such as national institutional arrangements or regional specialization (Coenen, 2015). While we fully acknowledge the relevance of studying such influences, especially if the purpose is to understand why innovation patterns and performance vary between places, we have chosen to focus our analysis on technological and sectoral influences.

2.2.2. Different types of influences

Context structures can have different types of influences on a focal TIS. Following Sandén and Hillman (2011), a distinction can be made between *mode* and *locus* of influence. The *mode of influence* describes whether a context structure influences the focal TIS in a positive or negative way (Bergek et al., 2015; Sandén and Hillman, 2011). In the transitions literature, much attention has been given to the negative influence of sectors on novelty generation in niches and TISs (Geels, 2002; Klitkou et al., 2015; Unruh, 2000; Wesseling and Van der Vooren, 2017). In more recent studies, however, the actual and potentially positive influence of established sectors has been highlighted (Haley, 2018; Leitch et al., 2019; Mäkitie et al., 2018). In a similar vein, the mode of interaction between different TISs has been described as complementary or competitive. Some technologies are complementary (Bergek et al., 2015) and actors developing related technologies sometimes "run in packs" to change general framework conditions (Bergek et al., 2008c). However, TISs can also compete for resources, legitimacy, and access to (niche) markets (Berggren et al., 2009; Dreher et al., 2016; Magnusson and Berggren, 2018; Suurs and Hekkert, 2009). In this paper, we focus on whether context structures enable or impede the focal TIS's functionality.

The *locus of influence* refers to where the influence emanates from. It has been argued that interdependencies between a focal TIS and related TISs and sectors are the result of structural couplings up- or downstream in the value chain (Bergek et al., 2015; Sandén and Hillman, 2011). Upstream interdependencies occur when technologies build on similar knowledge bases, use the same input materials or components, or are produced using the same manufacturing or process equipment. They also occur when firms and other actors are active in several technologies at the same time (Mäkitie et al., 2018; Sandén and Hillman, 2011). This is especially important for emerging TIS, which tend to be built up initially by actors moving in from other fields (Bergek and Jacobsson, 2003). Interdependencies can also relate to institutions, for example when a regulation originally designed for one technology is applied to (or excludes) another technology (Sandén and Hillman, 2011). Downstream interdependencies occur when technologies are used in the same applications and markets or are dependent on the same infrastructure and complementary products. Technologies can also be subjected to the same downstream norms and regulations, for example consumer preferences and public support schemes (Bergek et al., 2015; Sandén and Hillman, 2011).

However, structural overlaps do not necessarily mean that there is an influence from the context to the focal TIS. In some cases, sectoral actors that diversify into an emerging TIS contribute to developing new TIS-specific resources and strategies without much consideration of the resources, strategies and norms of their original sectors. Since such endogenous influences (Onufrey, 2017) are not truly contextual from the point of view of the focal TIS, they are not considered further in this paper. In other cases, such actors rather reproduce the development trajectories of their original sector, for example by transferring established knowledge, production

[2] More complex TISs could be seen as nested hierarchies of components and sub-systems (cf. Murmann and Frenken, 2006), where the functional dynamics of each sub-TIS is dependent on the pace and direction of development of other sub-TISs and the focal TIS as a whole. Instead of a context analysis, a more detailed analysis of interactions within the focal TIS could then be required.

[3] Global/international TISs are sometimes seen as geographical rather than technological context structures (cf. Bergek et al., 2015). However, we interpret the geographical dimension as primarily focused on where in scale and space different innovation processes take place and why, emphasizing the influence of local conditions, such as generally defined regional or national innovation systems in which spatial proximity (Boschma, 2005) between actors is an important aspect. In contrast, we are focused on the technological relatedness and value chain interdependencies between a focal TIS and its international counterpart, which we would argue is more a matter to of cognitive and organizational proximity (Boschma, 2005). We therefore think it makes more sense to treat the international TIS as a technological context in this case.

[4] Bergek et al. (2015) also discuss a fourth type of context structure, that is political, educational and financial systems providing specific system level assets, which they argue can influence the structural dynamics of a focal TIS and its context systems. As we are mainly interested in functional dynamics, we focus our analysis on how resulting policies and strategies influence the focal TIS via other context systems.

Table 1
Explanation of TIS functions and examples of associated sub-processes

Function	Description	Examples of associated sub-processes
Knowledge development and diffusion	Broadening and deepening of the knowledge base of a TIS and sharing of knowledge between actors within the system	Knowledge accumulation, diversification and convergence Development of markets for technology Knowledge acquisition, absorption, and integration Technological collaboration, communication and dissemination Learning by doing and using
Entrepreneurial experimentation	Problem-solving and uncertainty reduction through real-world, trial-and-error experiments with new technologies, applications and strategies.	Piloting and demonstration of new technologies Exploration of new applications and user contexts Business modelling
Guidance of the direction of search	Mechanisms that influence to what opportunities, problems and solutions supply-side actors apply their resources, encouraging them to engage in innovative work within a particular technological field and determining their strategic choices in that field.	Accumulation of incentives and pressures Identification and articulation of new technological and market opportunities Articulation of expectations Self-reinforcing mechanisms (e.g. coordination and network effects)
Market formation	The opening up of a space/arena in which goods and services can be exchanged in (semi-)structured ways between suppliers and buyers	Articulation of demand and preferences Product positioning by manufacturers Diffusion intermediation Development of rules of exchange Increasing returns to adoption
Resource mobilisation	The system's acquisition of different types of resources for innovation, most notably capital, competence and manpower, and material assets.	Public and private funding and financing mechanisms Education and training Development and exploitation of complementary assets and infrastructure
Legitimation	The process of gaining regulative, normative and cognitive legitimacy for the new technology, its proponents and the TIS as such in the eyes of relevant stakeholders.	Technology assessment validation, and standardisation Institutional adaptation and manipulation (e.g. lobbying) Changing norms and values in society Development of new institutions
Development of positive externalities	The creation of system-level utilities, which are available also to system actors that did not contribute to building them up.	Development of a pooled labour market Development of complementary technologies Emergence of specialized suppliers and intermediaries

Source: Bergek (2019) (adaptation of Bergek et al. (2008b)).

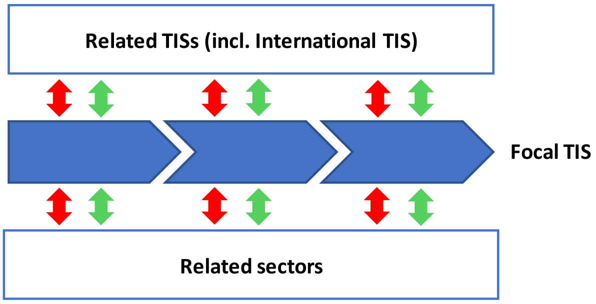

Fig. 1. TIS in technological and sectoral context.

processes, business models etc. to the focal TIS or exploiting existing sectoral self-reinforcing mechanisms (Onufrey and Bergek, 2015). This is the type of exogenous influences that we focus on in this paper.

2.3. Research questions

To sum up, previous literature has concluded that technological and sectoral contexts might have positive and negative influences on a focal TIS and that these can be related to up- or downstream structural overlaps. Some recent studies have explored some of these issues further, but many questions still remain with regard to the relative importance of different contexts and types of influences.

First, several of the empirical studies are limited to one context, most often a related industry or sector (cf. Haley, 2018; Hanson, 2018; Leitch et al., 2019; Mäkitie et al., 2018). Only a few include several related TISs (e.g. Dreher et al., 2016) or sectoral context structures (e.g. De Oliveira and Negro, 2019).

Second, most studies focus on one mode or locus of interaction. Most studies analyze *either* upstream interdependencies (e.g. common knowledge bases) (cf. Hanson, 2018; Leitch et al., 2019; Mäkitie et al., 2018) *or* downstream interdependencies (e.g. common product markets) (e.g. Dreher et al., 2016; Haley, 2018). Moreover, the latter focus solely on negative influences. One exception is the study by De Oliveira and Negro (2019), which focuses on how a focal TIS was influenced – positively and negatively – by related sectors, upstream and downstream (but does not include influences from related TISs).

As this brief review shows, the emerging literature on “TIS in context” has provided much needed insights into how a focal TIS is influenced by different types of contexts. However, more research is needed to understand the positive and negative consequences for a focal TIS of being linked up (both up- and downstream) to several related TISs and sectors at once. To contribute to our understanding of these issues, this article will answer the following research questions:

(1) What positive and negative influences do technological contexts (defined as related TISs) and sectoral contexts (defined as related systems of production, distribution and use), respectively, have on the functional pattern of a focal TIS?
(2) What up- and downstream interdependencies are the main sources of these influences?

We investigate these questions by studying a TIS in a very early (“embryonic”) phase of development, where context influences as described earlier can be expected to dominate. This allows us to further our understanding of the nature and importance of different context structures.

3. Research methodology

3.1. Study design and case selection

This article builds on a qualitative single case study. This research design is appropriate considering that the purpose of the paper is to identify and describe the existence of a particular phenomenon – in this case influences from context structures on a focal TIS (Eisenhardt and Graebner, 2007).

The case in focus is the embryonic TIS of mixed food waste (MFW) bio-succinate in Sweden, which we studied in the period of 2013—2017. Succinate (or succinic acid) is a predominantly petroleum-based bulk platform chemical[5] with an annual global production of 30000—50000 tonnes. A small share of the production is bio-succinate based on crops and occasionally homogeneous food waste (HFW). Bio-succinate produced from heterogeneous food waste such as MFW and from lignocelluloses, are technologies still in their infancy (Jansen and van Gulik, 2014; Lin et al., 2014). All bio-succinate developments are further embedded in a wider bio-based chemicals and materials development trajectory that compete on a market dominated by fossil chemicals (see Fig. 2).

In 2013, a national level network of actors was established to investigate the conditions for developing and producing platform chemicals from MFW in Sweden. This network was the result of the research programme “Developing high value platform chemicals

[5] Platform chemicals can be converted to a larger number of useful chemicals and products than conventional chemicals.

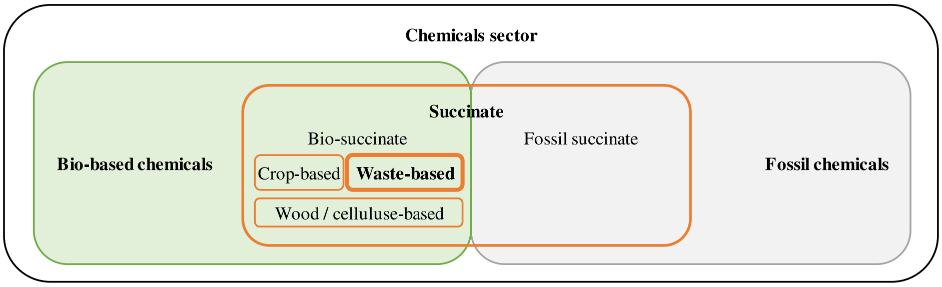

Fig. 2. MFW bio-succinate positioned in a wider bio-based and fossil chemicals and materials context.

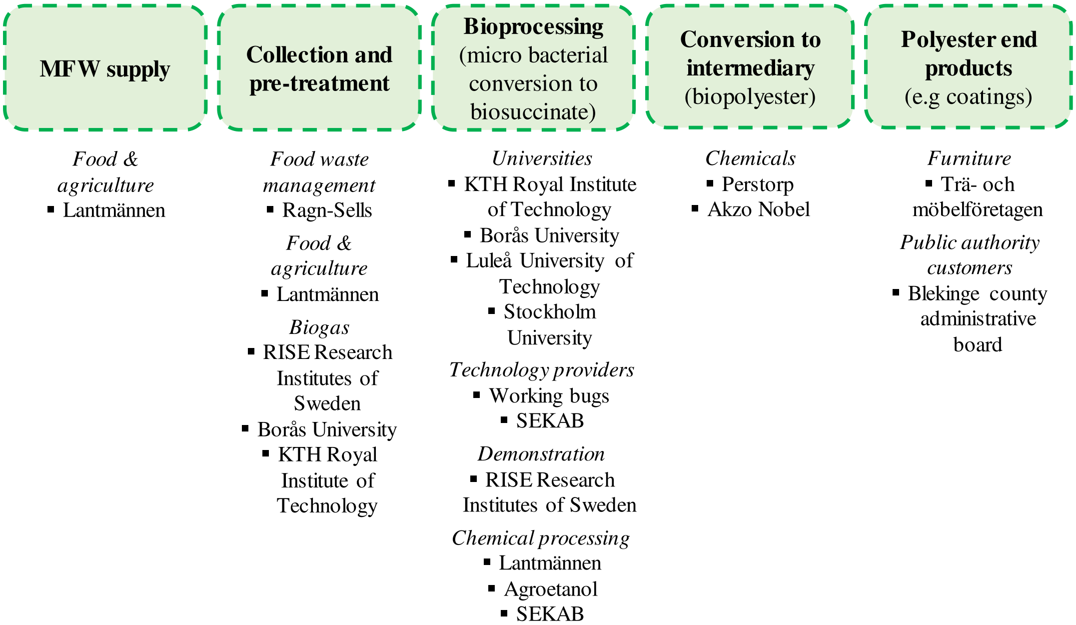

Fig. 3. Prospective MFW bio-succinate value chain and actor network.

into the biorefinery" (2013—2017), which was initiated by the waste management company Ragn-Sells and researchers in the field of bioprocesses at the Royal Institute of Technology (KTH).[6] While MFW bio-succinate is mainly aimed at the chemicals sector, the initiative included actors from several adjacent sectors that together covered all steps of the prospective value chain as shown in Fig. 3. The network selected bio-succinate as one of the most interesting options to develop from MFW. For the purpose of this paper, we view this network as the actor base of an embryonic TIS. With regard to institutional aspects of MFW bio-succinate development, there were no dedicated bio-succinate policies on the national level in the period studied (Nova-Institut, 2015; Statens energimyndighet, 2014). There were, however, national biochemical policies (see Section 4.2).

In relation to previous TIS studies, this is a somewhat extreme case, both in terms of its large structural (actor) overlaps with other sectors and its very early ("embryonic") stage of development. However, these features also make it a critical case – if we cannot find interesting information about interactions between a focal TIS and its context in this case, where we would expect context influences to dominate the functional pattern (Bergek et al., 2015, 2008c), then where would we find it (Flyvbjerg, 2006)?

Because the focal TIS hardly exists, it can perhaps be questioned whether a TIS analysis is relevant or even possible (Markard and Truffer, 2008). However, Bergek et al. (2008b) argue that because the innovation system framework is primarily an analytical tool, it can be applied even when a fully-fledged system does not exist in reality.

Relevant context structures were identified following the suggestions by Bergek et al. (2015) to focus on actual, empirically identified interdependencies. We traced the focal network's actor overlap with other TISs and sectors and also asked informants in two workshops (WS 2, 3) about relevant interdependencies between the development of MFW bio-succinate and various context structures.

[6] The programme was funded by Formas (the Swedish research council for sustainable development).

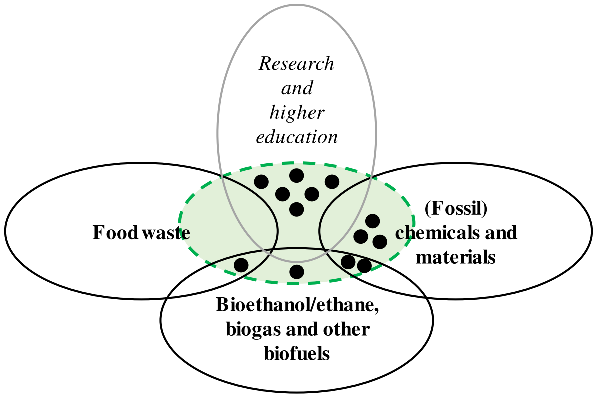

Fig. 4. Nascent network driving the development of MFW bio-succinate in Sweden (dotted green circle) and its overlapping context structures (black & circles) and other actor groups (grey circle).

Based on this, we selected three technological contexts ("other TISs") (the international bio-succinate TIS, bioethanol/ethane from crops and lignocellulose, and biogas from MFW) and two sectoral contexts (food waste and fossil chemicals/materials).[7]

One starting point was, thus, actor overlaps. As illustrated by Fig. 4, the MFW network actors have their main residence in one of two main established sectors, waste management (Ragn-Sells) and fossil chemicals and materials (Perstorp and Akzo Nobel), and/or are involved in one or more emerging technologies apart from bio-succinate, e.g. biogas (Lantmännen Agroetanol) and bioethanol and ethane (Lantmännen Agroetanol and SEKAB).[8] Context interdependencies also exist outside the current MFW network. Of particular importance for the purpose of this paper is the international bio-succinate TIS, which is more broadly defined (and much more mature) than the MFW TIS. Some actors, most notably universities and research institutes, interact with several sectors and TISs. To include all of these would not be feasible in this analysis, which is why we focus on the context structures mentioned above.

Fig. 5 describes the value chains of the focal TIS and the identified context structures. The embryonic nature of the focal actor-network as compared with the context structures is indicated by dotted lines in its (tentative) value chain. It also gives an overview of the most apparent up- and downstream interdependencies between the focal TIS and the context structures (as indicated by connecting frames), which further justify including them in the analysis. Frame 1 (blue) indicates that MFW bio-succinate relies on the same feedstock as biogas and that they get that feedstock from the food waste sector. Frame 2 (yellow) shows that MFW bio-succinate relies on similar pre-treatment technologies and related infrastructures as those developed by the waste and biogas systems. Bio-succinate could potentially even be produced together with biogas. Frame 3 (red) highlights a downstream interdependency in that bioethanol and the fossil chemicals and materials sector has relevant infrastructure in place for product development and chemical conversion of bio-succinate. Frame 4 (green) illustrates that the international (crop-based) bio-succinate TIS relies on different feedstocks but has similar process technologies and aims at the same applications and markets. Finally, Frame 5 (black) shows that MFW bio-succinate shares the same markets as bioethanol/ethane and the fossil chemicals and materials sector.

3.2. Data collection and analysis

While the focus of this paper is to gain insights into the contextual influence on the MFW case, the research reported in this paper originates in work done within two broader research projects on platform chemicals and bio refineries, conducted from June 2014 to April 2017. As part of these projects, a traditional structural and functional TIS analysis was first carried out according to the scheme of analysis presented by Bergek et al. (2008b). In this analysis, the importance of contextual influences became apparent and it was therefore decided to focus the present paper on this more specific topic.

Data were collected from several sources and through different methods. Primary data sources include interviews, workshops and a meeting (see Table 2 for an overview). The interviews were carried out with key stakeholders from SMEs, industry, university and research institutes in the field of bio-based platform chemicals and were largely semi-structured in nature. Informants were identified by means of a snow-balling method. The workshops and meetings included stakeholders from industry, research institutes and universities. All interview, workshop and meeting material has been anonymized at the request of single informants. Primary data were complemented by a literature review, which covered academic literature, policy reports and papers as well as various media sources (mainly from the Internet) discussing the focal TIS and the related context structures analysed in this paper.

We used a qualitative, interpretative approach to data analysis, in which information from interviews and secondary sources was

[7] We did not get any indication from the interviews that the actors' embeddedness in specific local contexts had any substantial influence on the emerging functionality of the focal TIS. This fed into our decision to not include geographical context structures in the analysis (see Section 2).

[8] Lantmännen is an agricultural cooperative owned by Swedish farmers. There was, thus, an actor overlap between the MFW bio-succinate TIS and the agriculture sector. However, Lantmännen's involvement in the network was motivated mainly by an interest in biofuels and limited to their subsidiary Lantmännen Agroetanol. We therefore decided not to include the agriculture sector in our analysis.

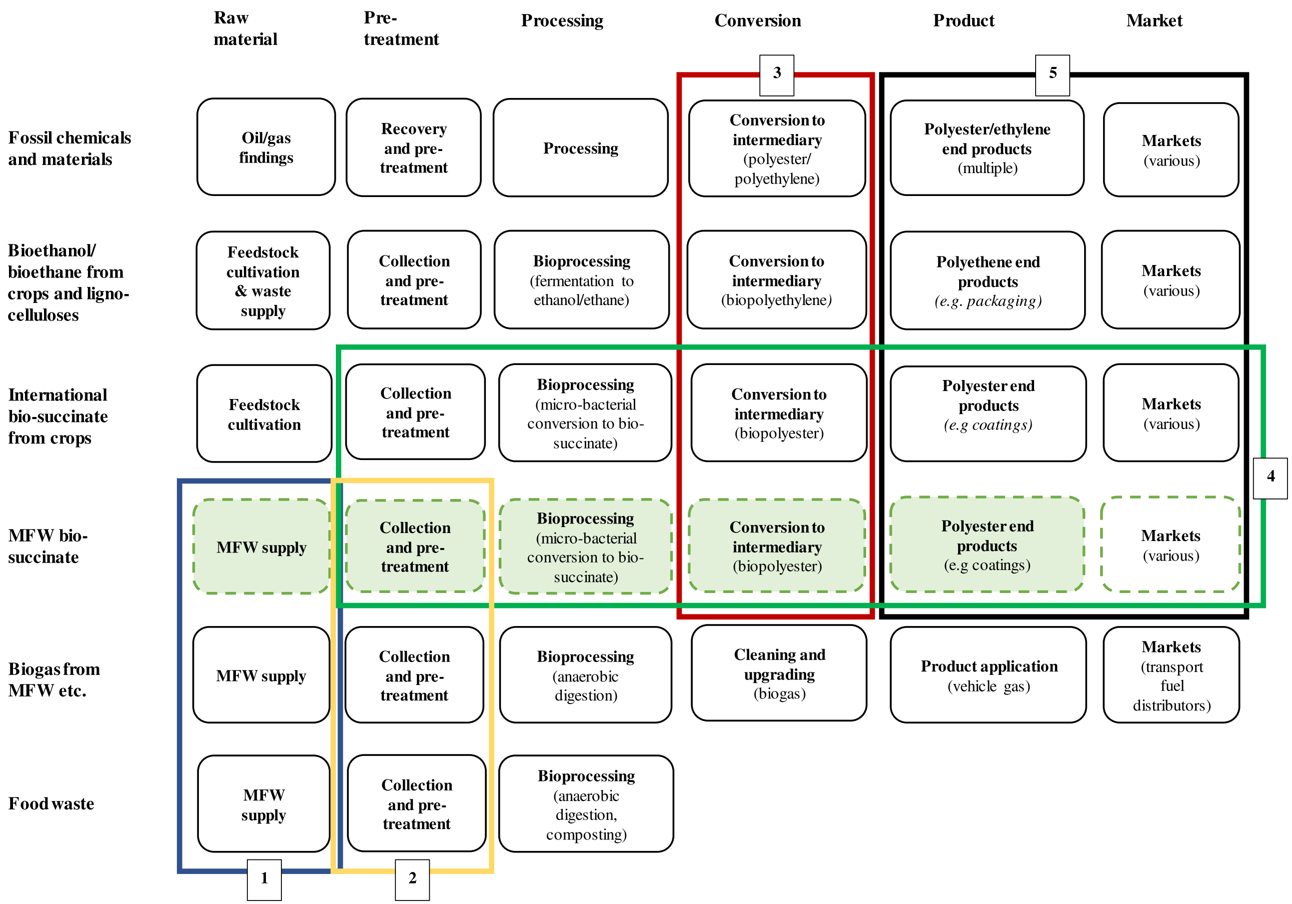

Fig. 5. Value chains of the MFW bio-succinate system and its key context structures.

Table 2
Overview of data sources

Data source	Reference in text	Type of organization/event
Informant interviews	A	Research institute
	B	Research institute
	C	Technical university
	D	Technical university
	E	Trade organisation
	F	Chemical industry
	G	Chemical industry
	H	Research institute
	I	University
	J	Chemical company
	K	Chemical industry
	L	Chemical company
	M	Agricultural industry
	N	County Council
	O	Technical university
	P	Research institute
Workshops and meetings (WS)	1	Workshop on advanced biorefineries, Stockholm
	2	Workshop on MFW bio-succinate value chain, Skype
	3	Workshop on MFW bio-succinate value chain at KTH, Stockholm
	4	Workshop on use of food waste for biochemicals production at Ragn-Sells, Heljestorp
	5	Workshop on bio-succinate at Annual project meeting, Stockholm
	6	Annual project meeting on Platform chemicals from mixed food waste, Stockholm

compared with the theoretical definitions of the functions and their associated sub-processes (as described in Section 2) to understand what influenced functions and how. Due to the embryonic phase of development, most of the identified empirical evidence was related to emergent sub-processes and mechanisms (e.g. awareness creation and demand articulation for market formation) rather than explicit activities and outputs (e.g. sales data). This is in line with our definition of functions as emergent properties. We used information from interviews and other sources to understand the actual impact of the identified factors and mechanisms on the functions. For example, if actors described an R&D program as an important source of funding, we interpreted this as 'resource mobilization'. If they also described it as an important reason for entering bio-succinate development or choosing a particular technology path, we interpreted it as 'guidance of the direction of search' as well. Consequently, each factor or mechanism was not assigned exclusively to one specific function.

To answer the specific research questions of this paper, data from the original TIS analysis were re-analysed using our analytical framework. We first identified exogenous influences from the selected context structures on the functions. We then characterized each influence in term of its mode of influence (i.e. positive or negative) and its locus of influence (i.e. upstream or downstream).

4. Context structures and their influence on the functions of the focal TIS

This section analyses how the identified context structures influence the focal TIS. This is done by mapping the positive and negative up- and downstream influences on the functions of the embryonic Swedish MFW bio-succinate TIS from the context structures identified in Section 3. For each context structure, only functions where evidence of exogenous influences was found are included in the analysis. The 'development of positive externalities' function is not discussed at all as no such dynamics had appeared at the point of study.

4.1. The international bio-succinate (and biochemicals) innovation system(s)

At an international level, we can identify a more broadly defined bio-succinate TIS, which at the point of study had commercial production of crop-based feedstock and ran some R&D initiatives with bio-succinate from homogenous food waste (HFW). The key actors involved in the crop based international bio-succinate TIS were chemical industries such as Reverdia, Succinity, Bioamber and Myriant (Choi et al., 2015). BioAmber was also developing waste-based bio-succinate (Bioamber, n.d.). In the studied period, there were expectations that bio-succinate would not only substitute the current fossil succinate production, but also a great number of other fossil chemicals and materials in the future (Choi et al., 2015; Jansen and van Gulik, 2014; Lane, 2015).

Knowledge development & diffusion and entrepreneurial experimentation. Internationally, companies such as Starbucks and Heinz experimented with HFW bio-succinate, which relied on mature technical processes (Coxworth, 2012; Ford, 2014; Uçkun Kıran et al., 2015). There was also increasing research and experimentation with a range of MFW requiring more advanced bio-succinate process techniques (Lin et al., 2014; Nova-Institut, 2015; Uçkun Kıran et al., 2015). However, to our knowledge there had only been one successful lab scale experiment with MFW to succinate at the point of study (Sun et al., 2014). Developments and experiments by the international bio-succinate TIS accumulated useful knowledge to be exploited by the Swedish MFW bio-succinate TIS, although we couldn't find any concrete evidence of actual knowledge spill-overs or acquisitions. International knowledge development and experimental activities were hampered by a lack of policy for bio-based chemicals and materials, in particular for MFW bio-succinate, although some broader declarations of intent and (limited) R&D funds at the EU level related to the broader biochemical area (Nova-Institut, 2015) laid a basis for future knowledge spill-overs to Swedish actors (Informants D, H).

Guidance of the direction of search. Even through the Swedish MFW bio-succinate network was still quite small, positive trends at the international scale were slowly reducing barriers to entry. For example, the economic expectations of bio-based platform chemicals in general, e.g. voiced by the US Department of Energy (Choi et al., 2015), had gained increased followers over time. Moreover, an increasing range of EU strategies and initiatives were being developed, such as declarations of intent towards the development of bio-based platform chemicals and related materials as a means to increase economic growth (European Bioplastics, n.d.; Nova-Institut, 2015). These emerging positive expectations and incentives implied that actors from the biofuel context systems, in particular the bioethanol/ethane TIS described below, were induced to consider the inclusion of bio-based chemicals in their production stream.

Market formation. In the studied period, there were no dedicated bio-succinate policies for market promotion at the EU level (Nova-Institut, 2015; Statens energimyndighet, 2014), but there were policies related to the broader biochemical area. For example, the Lead Markets Initiative for Bio-based Products included market promoting regulations and incentives as well as public procurement directed at bio-based materials (Nova-Institut, 2015). While such policies held a promise of future market formation, the successful commercialization of crop-based bio-succinate and the many projected production plants (e.g. Choi et al., 2015; Jansen and van Gulik, 2014; Lane, 2015) demonstrated that there already was an articulated (and maybe also growing) demand for bio-succinate. In principle, this niche market was also available to MFW bio-succinate. However, from the point of view of the Swedish actors, successful access to this market was not guaranteed. Crop-based bio-succinate was much cheaper and more mature than the waste-based alternatives and, thus, a strong competitor. More importantly, the promotion of waste feedstock at the EU level implied that the future competition over market shares from European food waste succinate would most likely be worse than that from crop-based succinate. Moreover, the leading bio-succinate actor, BioAmber, already had a working value chain in place that only needed to be optimized for waste and was, thus, way ahead of the Swedish actors.

Resource mobilization. Sweden lacked the physical resources of a biotech and bioprocessing infrastructure able to scale up production of the cellular strains needed for bio-succinate production (Informant C; WS 5). Internationally, bio-succinate producing companies such as BioAmber already had a working value chain in place and could take on this production. Regarding financial resources, some R&D funds were available at the EU level, albeit targeted at the broader biochemical area rather than specifically at MFW bio-succinate development (Nova-Institut, 2015; Informants D, G). In the period studied, at least one of the Swedish MFW bio-succinate TIS actors (RISE) was able to access these funds for bio-succinate development (EC, 2020).

Legitimation. The international producers of bio-succinate from crops had started to explore the potential of using waste feedstock (Nova-Institut, 2015). This norm-challenging practice indicated a growing legitimacy for bio-succinate from waste, including MFW. Moreover, some progress had been made at the EU level to develop standards for the broader biochemical area, which resulted in similar developments in Sweden (Swedish standards institute, n.d.; Informant L).

4.2. The (fossil) chemicals and materials sector

The fossil chemicals and materials sector is a well-established sectoral system of production and consumption, which dominated succinic acid production in the period studied (IEA, 2017; Jansen and van Gulik, 2014). In Sweden, the key actors were (and are) the chemical industry, which produces fossil-based chemicals and materials, a variety of companies producing related end products, and the consumers using them (Statens energimyndighet, 2017). Its technologies were mature and there was a well-developed and supportive institutional framework of regulations, norms and standards contributing to economies of scale.

Knowledge development & diffusion and entrepreneurial experimentation. Actors in the chemicals and materials sector held a lot of relevant knowledge for the development of MFW bio-succinate. However, in the period studied there was limited technological collaboration between bioprocess researchers and companies in the sector (Informant C, E, WS 2, 3). According to MFW bio-succinate actors (WS 2, 3), this was due in part to the complex and swiftly changing chemicals market which created the need for high secrecy. This lack of collaboration hampered knowledge diffusion and was identified as a general obstacle for Swedish development of bio-based fuels, chemicals and materials (Joelsson et al., 2015; Statens energimyndighet, 2014; Wännström et al., 2015).

Guidance of the direction of search. The chemicals and materials market was (and is) highly volatile and competitive, which made it hard for sectoral actors to identify the most promising opportunities and determine which value chain and processes to invest in. The resulting uncertainties and risks limited actor engagement in radical innovations such as MFW bio-succinate, which in the period studied hardly enjoyed any institutional incentives in comparison with its fossil counterpart (WS 2, Informant F). This problem was further aggravated by the lack of collaboration in the sector, as mentioned above, which hampered the efficient definition of needs and potential solutions with regard to bio-based chemicals production (Informant C, E; WS 2, 3). However, tougher climate change mitigation ambitions at various policy levels and among industry actors were expected to aid guidance for bio-based chemicals (Nova-Institut, 2015). While national level mitigation policies primarily focused on transport and energy rather than chemicals (Miljödepartementet, 2014; Miljömålsberedningen, 2016), the Chemical and Industrial cluster of West Sweden had an expressed ambition to become fossil free by 2030 (AGA et al., n.d.). The development of bio-based platform chemicals was seen as key to realizing this ambition. In addition, increased demand for and use of bio plastics by some large customers, e.g. Tetra Pak, Valio and Ikea (IKEM, 2015), also provided incentives for chemicals companies to engage with bio-based options like bio-succinate.

Market formation. The fossil chemicals and materials sector was (and is) a key competitor to all forms of bio-succinate, due to its generally lower feedstock prices, mature technology processes and infrastructure. In the period studied, some of the product markets that were suitable for bio-succinate applications showed a strong lock-in to fossil products likely to block the development of bio-based products. These were products, such as paints and glues, where resulting changes in product properties were seen as negative by users

(WS 3). However, there was a small but increasing demand for bioplastics. While bio-based plastics only had a 1% market share at that time, it was seen as a potential niche market for bio-succinate (Hannerz and Närman, 2014; IKEM, n.d.; WS 2, 3). In part, the bio-plastics demand was driven by climate change mitigation ambitions and efforts. For example, there was an articulated demand for more climate-friendly products close to the end user, which resulted in people paying a premium price for plastic bags from bio-polyethylene and bottles from bio-polyethylene terephthalate (PET) (European bioplastics, n.d.; Nova-Institut, 2015). There were also green public procurement schemes for products to national and local authorities. The US was a forerunner with the Biopreferred programme, which required procurement of 97 product categories with bio-based content by federal states (USDA, n.d.). The EU Lead Market Initiative on bio-based products expressed the intention to develop similar procurement incentives (EC, 2016a). There were also a growing number of Swedish public procurement initiatives at the municipal and regional scale related to bio-polymer products in the healthcare sector (Dalenstam et al., 2014; Hannerz and Närman, 2014; Informant N). Moreover, according to the Nova institute (2015) and Bioplastics Europe (n.d.) the trend of ever-growing consumption of fuels, chemicals and materials would increase bio-based chemicals demand in general, since the fossil sector would not be able to meet the increasing demand on its own.

Resource mobilization. In terms of physical resources, the chemical industry's production infrastructure, most notably conversion processes to intermediary and end products, could be used to realize future production of bio-based chemicals such as MFW bio-succinate (WS 3, 6). Since some of these production infrastructures were owned by MFW bio-succinate network actors, they should have been relatively easy to exploit. However, the flexibility of the industry's processes was limited. Only two of the network members, Perstorp and Akzo, had basic infrastructural conditions in place to apply cellular bioprocesses, which was far from sufficient. Moreover, chemical processes were difficult to change due to long term (+10 years) depreciation periods of previous infrastructure investments. There was a concern in the MFW bio-succinate network that this lock-in of the production processes to fossil feedstock would hamper future experimentation and upscaling of bio-based chemicals (WS 1, 3). A major challenge was the hesitance of the chemical industry to accept bio-based material into their current production infrastructure, as this would require the bio-succinate to meet current fossil standards regarding pureness and stability. With regard to human resources, an analysis on Swedish biorefinery development (Statens energimyndighet, 2014) indicated that Sweden ran a risk of having too few chemical engineers to facilitate the expansion of bio-based chemical production in a long term perspective. This was (partly) due to a reduction in chemical engineering education at Swedish universities (WS 1). Finally, with regard to financial resources there were initiatives on the European level, e.g. the FP7, the Knowledge Based Bio-Economy (KBBE), and the Horizon 2020 programmes, which aimed at supporting a green European chemical and manufacturing industry by increasing innovation and international competitiveness within bio-based materials and plastics (Nova-Institut, 2015).

Legitimation. There was already certain legitimacy for bio-based chemicals within the chemical industry. This legitimacy was expected to increase due to changing norms and values reflected in several trends described above, including political agendas for climate change mitigation and energy security as well as increasing market demand for bio-based chemicals and materials. Moreover, legitimacy creation was also visible in attempts to change institutions. For example, the chemical industry association IKEM and the Chemical and Material Cluster of Stenungsund were disseminating information and lobbying for national level support for bio-based chemicals and materials in general, which was expected to benefit MFW bio-succinate (AGA et al., n.d.; IKEM, n.d.; Informant L). In addition, the chemical company SEKAB was promoting standards for further bioplastics development at the EU level, by being part of the development of the Lead Markets Initiative for bio-based products (Informant L). However, as mentioned above quality standards for bio-succinate in the fossil chemicals sector was a key bottleneck for producing MWF bio-succinate at a larger scale (WS 1, 3, 4).

4.3. The food waste sector

The food waste sector involves production, collection and management of waste. At the time of study, food waste in Sweden was either incinerated or biologically recycled. The primary biological recycling practice was anaerobic digestion to biogas followed by composting (SMED, 2016). The key actors were households, restaurants, stores and food industry producing waste and various municipality owned waste collection and management companies (Avfall Sverige, 2011).

Market formation. At the time of the study, the increased international attention to resource efficiency and biomass cascading, which was visible in the EU Bioeconomy strategy (EC, 2012) and the Circular economy package (Bourguignon, 2017), constituted an early articulation of demand as it was expected to stimulate demand for waste-based bioeconomy solutions and steer the international bio-succinate demand from crops to various waste-based feedstocks.

Resource mobilization. The MFW bio-succinate TIS actors were trying to mobilize physical resources from related sectors. This included attempts to exploit Ragn-Sells's existing infrastructure for food waste collection and pre-treatment to make a food waste slurry, which was also used for biogas production. Access to other assets, such as raw materials (i.e. food waste) was enabled by the clear norms and incentives regarding the separation of MFW. Over 70% of Swedish municipalities offered separate collection of MFW from households and companies, although this was mostly voluntary for households with only a small financial compensation in return (Avfall Sverige, 2016, 2011). In addition, the EU bioeconomy strategy promoted the use of waste feedstock, arguing that crop-based chemicals and fuels were not the most sustainable alternatives because they compete with food and arable land (EC, 2012, 2009). The use of low-grade waste feedstock, such as MFW, instead of crops was also in line with the biomass cascading principle of the EU waste hierarchy of recycling in the Circular economy package (Bourguignon, 2017; EC, 2015). However, there were also issues preventing access to raw materials. There were strong norms for using food waste for biogas production, which were realised in the form of long-term contracts between waste management firms and biogas producers (WS 3, 4; Informant A, C). Moreover, there was an increased political focus in Sweden and the EU on resource efficiency and food waste reduction, which could limit the amount and quality of food waste available for MFW bio-succinate production. For example, while the Circular economy package promoted the use of food waste it also argued for food waste reduction in line with the EU and UN targets of halving food waste by 2020 and 2030 respectively (EC, 2015, p. 9, 2011, p. 18). Sweden had similar goals and rules for food waste in place (Regeringskansliet, 2015). There was a national goal that at least 50% of all food waste should be biologically treated by 2018, of which 40% should be treated to recover energy as well (Miljödepartementet, 2012). This implied that at least 40% of the food waste had to be used for biogas production (Jordbruksverket et al., n.d.). This was yet another indication of the strong interdependency between the waste sector and the biogas TIS.

Legitimation. Even though the general societal norms and values saw taking care of food waste as positive when waste was available, the growing political and public focus on reduction of food waste implied that making food waste a major resource for the production of chemicals might not be unambiguously positive since it would be better if food waste did not exist at all.

4.4. The bioethanol/ethane TIS

Swedish development of bioethanol as a transport fuel was largely based on grain, and such ethanol was already produced by Lantmännen Agroetanol. However, most bioethanol/ethane used in Sweden was imported (Informant M). There was also small-scale production of bioethanol from waste streams from sulphite pulp mills and starch rich HFW (Ekbom, 2016). More advanced lignocellulose ethanol had been demonstrated together with a range of other bio-based fuels and chemicals at a plant in Örnsköldsvik, owned by RISE Processum. While there had been a lot of R&D activities in the advanced lignocellulose ethanol field and, more recently, ethane and polymers, involving actors such as researchers, chemical industry (e.g. Sekab), municipalities and government agencies, it was not yet commercially competitive (Ekbom, 2016; Miljö och Energidepartementet, 2013).

Guidance of the direction of search. The Swedish biofuel agenda had recently been widened to include chemicals in biorefinery solutions, as demonstrated by the Swedish Energy Agency's ethanol cellulose programme (Statens energimyndighet, 2012) and other government-funded biorefinery initiatives.[9] This made it possible to apply for funding for bio-based chemicals as long as they fitted the biofuel research agenda (Formas et al., 2012a; Miljömålsberedningen, 2016; Statens energimyndighet, 2012). This incentivised some bio-succinate actors to focus on lignocellulose waste streams instead of MFW (Informant P).

Market formation. Similar to the food waste sector, there was a growing demand for waste-based bioeconomy solutions articulated in the EU Renewable energy and ILUC directives. While these directives focused on biofuels, network actors expected them to steer the international bio-succinate demand from crops to various waste-based feedstocks and, thus, saw them as an articulation of future demand. MFW succinate could find a place on this market if sufficiently competitive in price. However, in line with the Swedish bioeconomy agenda, market incentives targeted primarily the realization of biofuels and biochemicals from lignocellulose rather than grain and other waste feedstocks (Formas et al., 2012b; Miljömålsberedningen, 2016; Informant D; WS 6). This implied that the Swedish market prioritized lignocellulose chemicals, such as bioethane, over MFW bio-succinate.

Resource mobilization. The MFW bio-succinate TIS actors were trying to mobilize physical resources from related TISs. One example was the discussions with the network actor Lantmännen Agroetanol about the potential of using their existing ethanol infrastructure for co-production of bio-succinate (WS 4). With regard to raw materials, there was political pressure on bioethanol and other biofuels to use waste feedstock (EC, 2016; Nova-Institut, 2015). While this created funding opportunities for MFW bio-succinate, the potential to exploit these opportunities were limited by the strong Swedish focus on lignocellulose waste feedstock and the political pressure to reduce waste (WS 6; Informant D, H, P). In addition, it was expected that increased focus on using waste for fuels would increase competition and reduce the availability of food waste as a raw material (EC, 2016; Nova-Institut, 2015).

4.5. The biogas TIS

At the time of study, the Swedish biogas TIS was (and still is) centred on anaerobic digestion of mainly sewage sludge and food waste. Consequently, the key actors were municipally owned wastewater treatment plants and waste management companies. The majority of the biogas produced was used to substitute fossil fuels in the transport sector (Statens energimyndighet, 2016).

Guidance of the direction of search. In contrast to other commercial biofuel systems, biogas production had economic feasibility problems at the time of the study which created opportunities for MFW platform chemicals such as bio-succinate (Larsson and Grönkvist, 2013). Market competition was harsh due to cheap biogas imports (Skog et al., 2017), and together with the increased attention for biorefinery solutions as an opportunity to propel the bioeconomy (Formas et al., 2012b; Nova-Institut, 2015; Statens energimyndighet, 2012), this provided increased incentives for biogas TIS actors to consider co-production of platform chemicals to improve their finances.

Market formation. The growing articulation of demand for waste-based bioeconomy solutions – which as earlier mentioned was related to biofuels like biogas and bioethanol – was expected to steer the international bio-succinate demand from crops towards various waste-based feedstocks, including MFW.

Resource mobilization. As previously mentioned, MFW bio-succinate TIS actors were trying to mobilize physical resources from existing food waste collection and pre-treatment infrastructures, which were run by the food waste sector but primarily used for biogas

[9] Other examples of the widening biofuel agenda towards biochemicals are Mistra financed "Greenchem" (Mistra, 2011), Vinnova financed innovation agendas "Bio material in healthcare" (Hannerz and Närman, 2014) and "Skogskemi" (Joelsson et al., 2015) and its strategic innovation programme "BioInnovation" (Wännström et al., 2015), Formas financed "Bioethanol, bioethylene och biopolyethylene" project (Formas, 2014) and the "High value platform chemicals into the biorefinery" financing this research (Larsson, 2013).

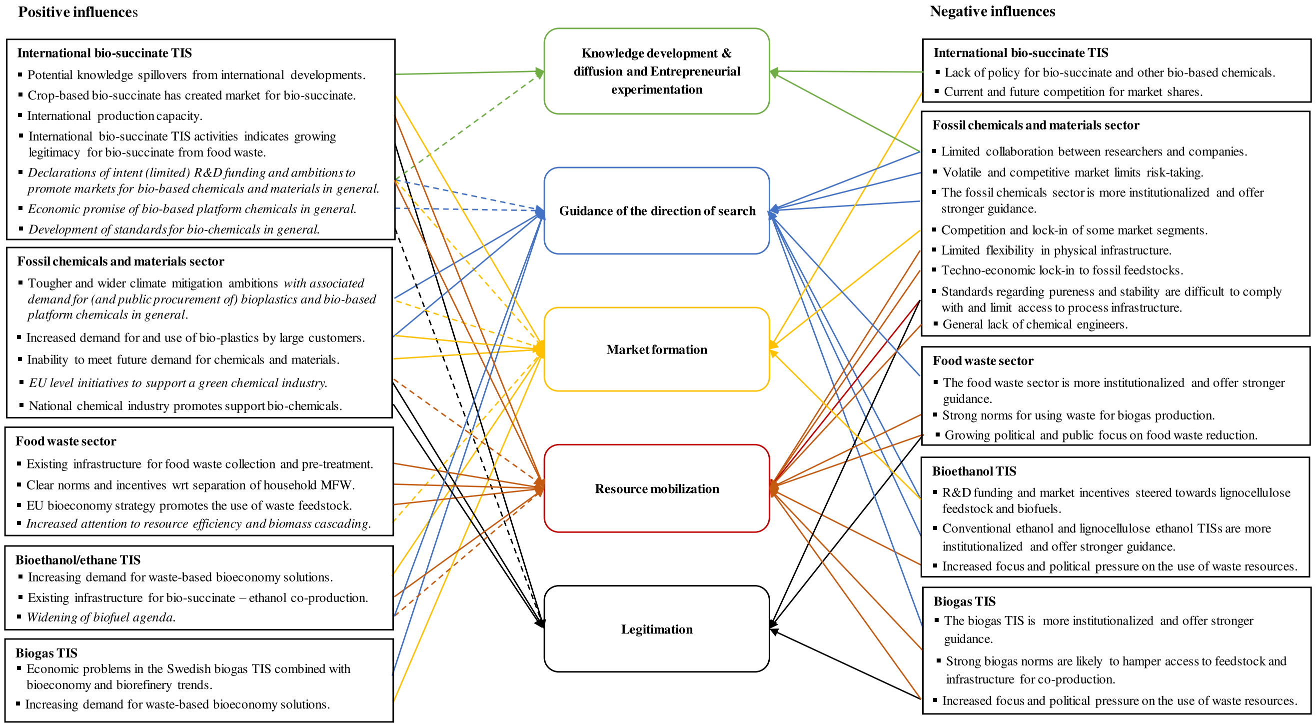

Fig. 6. Influence of context structures on functions of the MFW bio-succinate TIS (influences written in italics are more tentative)

production (Avfall Sverige, 2016). Building on the abovementioned bioeconomy and biorefinery trend in Sweden, the MFW bio-succinate actors expected that the co-production of bio-succinate and biogas could increase revenues and resource efficiency (Larsson, 2013). However, the biogas TIS restricted the bio-succinate TIS's access to the necessary food waste raw material. As mentioned above, there were established norms and contracts for using food waste for biogas production. Moreover, there were legal pressures on biofuels systems (including biogas) to use waste feedstock, which increased competition and reduced the availability of food waste even more (EC, 2016; Nova-Institut, 2015).

5. Discussion

The analysis in Section 4 shows that the functional pattern of the Swedish MFW bio-succinate TIS was heavily influenced by exogenous influences from the identified technological and sectoral context structures (as expected). These influences are summarized in Fig. 6 and discussed further in the following two sub-sections.

5.1. The influence of context structures on the functional pattern

Our first research question was what positive and negative influences technological contexts (defined as related TISs (including the international TIS)) and sectoral contexts (defined as related systems of production, distribution, and use) have on the functional pattern of a focal TIS.

As Fig. 6 shows, in this case there does not seem to be any clear pattern of interaction in terms of which context structures influence which functions. In the period studied, guidance of the direction of search, market formation and legitimation were all influenced both by technological and sectoral contexts, whereas knowledge development and diffusion and resource mobilization were primarily influenced by technological contexts. Moreover, we found no clear relationship between mode of influence and context structure type. Instead, all the analysed context structures had both positive and negative influences on the focal TIS.

Some interesting observations could nevertheless be made. The analysis shows strong and diverse influences from the identified sectoral contexts on the focal TIS. This contrasts with some previous studies, which have suggested that sectoral influences may not be very important in early phases of development of new (niche) innovations and that structural tensions between the emerging system and established regimes occurs as the system grows (cf. Dewald and Fromhold-Eisebith, 2015; Haley, 2018). Moreover, it is noteworthy that the main downstream sector, the (fossil) chemicals and materials sector, not only influenced the focal TIS negatively, because of various techno-economic-institutional lock-ins (as could be expected based on previous transitions literature), but also had some positive influences in terms of guidance of the direction of search, market formation and legitimation.

With regard to technological contexts, the identified influence of the international bio-succinate TIS seems to contradict some of the geography of transitions literature. While it has been suggested that the formative phases of TIS development is associated mainly with local R&D and production combined with national policy design (Dewald and Fromhold-Eisebith, 2015), the MFW bio-succinate case shows that the international scale can have an important influence even on an embryonic TIS, in terms of potential knowledge and technology spillovers, market formation, and legitimation. Moreover, policies at the international level (e.g. declarations of intent and standards) can provide important guidance of the direction of search of national actors.

Considering the functional analysis as a whole, we see three main channels through which technological and sectoral context structures influence the focal TIS:

- *Resource availability and accessibility*. The Swedish MFW bio-succinate case confirms that related technological and sectoral context structures may control resources that could be redeployed in a focal TIS (e.g. De Oliveira and Negro, 2019; Leitch et al., 2019; Mäkitie et al., 2018). Indeed, relevant knowledge, funding, and physical resources were available in the international TIS, the bioethanol/ethane TIS, and the biogas TIS, as well as in the fossil chemicals and food waste sectors. However, our study also highlights that the characteristics of the context structures can limit the focal TISs access to such resources. Most notably, sectoral resources might be too inflexible or locked-in to established technologies, standards, and use patterns to be exploitable for the purpose of developing new technologies. Moreover, the MWF bio-succinate case illustrates that actors from related technological and sectoral contexts that are involved in an emerging TIS are not necessarily willing or able to put their existing resources at the TIS's disposal. This supports previous findings that structural (actor) overlaps do not automatically result in resource redeployment (Leitch et al., 2019; Mäkitie et al., 2018). We will discuss this further in the next section.
- *Market conditions*. Related technological and sectoral context structures can influence the market conditions for a focal TIS, for example in terms of investment patterns and customer preferences (De Oliveira and Negro, 2019; Wicki and Hansen, 2017). Our study shows that such influences can come in the form of spillovers of a combination of specific and broader forms of demand and involve several context structures. For example, in the MFW bio-succinate case, articulation of demand for bio-succinate specifically (international TIS) co-existed with growing niche markets for bio-based plastics (fossil chemicals and materials sector), and demand for waste-based bioeconomy solutions (food waste sector, bioethanol/ethane TIS, and biogas TIS). These niche markets were to a large extent the result of economic and environmental pressures on the respective context structure. This supports the idea that context structures can translate external (landscape) events to a focal TIS (De Oliveira and Negro, 2019). However, in our case this translation was not only done by sectoral context structures but also by related TISs. The MFW bio-succinate case also indicates that context structures influence the ability of a focal TIS to exploit favourable market conditions. In this regard, our study especially highlights the importance of competition over market shares and policy support with related TISs and sectors, which the

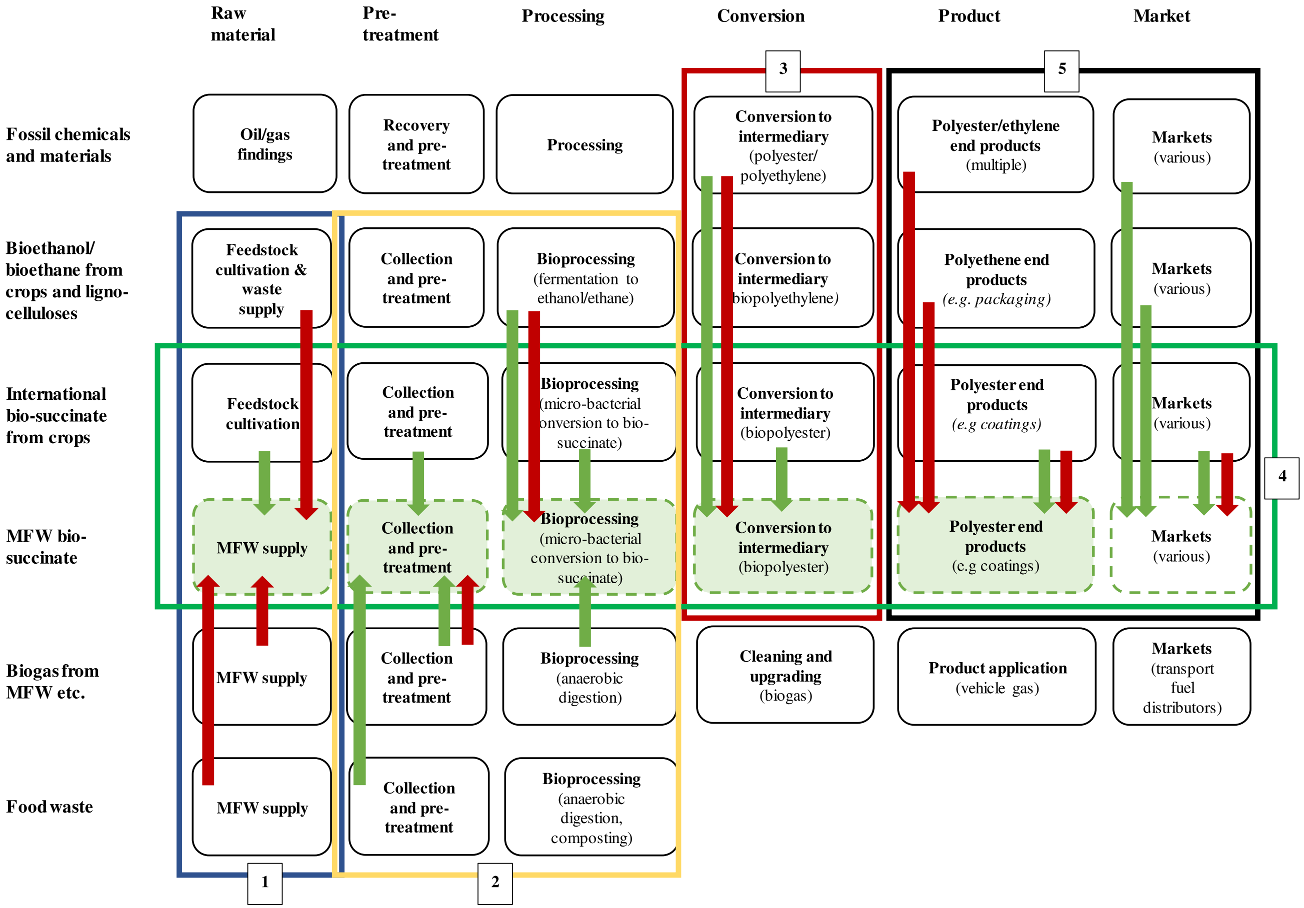

Fig. 7. Positive (green/light arrows) and negative (red/dark arrows) influences by various sectoral and technological context structuresConclusions and implications

embryonic focal TIS (as compared with the much more institutionalized related context structures) was not able to handle (although this did not seem to discourage the network actors from trying).

- *Wider selection environment.* In addition to market conditions, context structures can influence other aspects of the selection environment, such as problem agendas, technological trajectories, and institutional pressures and incentives (Bergek et al., 2015; De Oliveira and Negro, 2019; Mäkitie et al., 2018; Wicki and Hansen, 2017). This study shows that a focal TIS can be subjected to multiple and contradictory signals as a consequence of conflicting contextual influences on the selection environment. On the one hand, our findings demonstrate how economic and environmental trends in related TISs and sectors can work together to open up windows of opportunity for a focal TIS. In the MFW bio-succinate case, the economic promise of bio-chemicals (international TIS), increased demand for bio-plastics (fossil chemicals and materials sector), and economic problems in related TISs (biogas TIS) created positive expectations about the future economic prospects of bio-succinate. This coincided with political environmental ambitions and initiatives to mitigate climate change (fossil chemicals and materials sector) and to promote resource efficiency and use of waste-based feedstocks (food waste sector). One the other hand, the study highlights the many ways technological and sectoral context structures can tilt the selection environment to the disadvantage of the focal TIS. In particular, the MFW bio-succinate case shows how vulnerable an embryonic TIS can be when surrounded by more institutionalized context structures that provide stronger guidance for actors. While previous transitions literature emphasizes the high degree of institutionalization of sectors in the form of sociotechnical regimes, we see evidence of similar challenges in relation to related TISs (the biogas and bioethanol/ethane TISs). This supports previous claims from some authors that more mature TISs can outcompete less mature TISs (Magnusson and Berggren, 2018).

5.2. Context structures' influence on the value chain

The second research question of this paper was what up- and downstream interdependencies are the main sources of the context structures' influence on the focal TIS. Based on the results from the functional analysis, we revised Fig. 5 (see Fig. 7, where positive and negative influences are indicated by green/light and red/dark arrows respectively).

- *Frame 1 (blue)* refers to the upstream interdependency between the focal TIS, the food waste sector, and the biogas TIS in terms of a common food waste feedstock. This had a negative influence in the form of competition for resources and pressures to reduce food waste in society. Compared with Fig. 3, the frame now also includes the bioethanol/ethane TIS, since the analysis showed that it was part of the same bioeconomy/biorefinery discourse as food waste and biogas. This discourse steered attention (and funding) away from bio-succinate to biofuels and from MFW to other waste feedstocks.
- *Frame 2 (yellow)* highlights that the MFW bio-succinate TIS could benefit from existing norms and infrastructures for food waste separation, collection and pre-treatment related to the food waste sector and the biogas TIS and be co-produced with biogas and/or bioethanol. This positive influence was further strengthened by the growing bioeconomy and biorefinery trend. However, access to infrastructures was restricted by strong norms to use food waste for biogas production. Moreover, the bioethanol/ethane TIS contributed to steering R&D funding towards other feedstocks and applications.
- *Frame 3 (red)* confirms the downstream interdependency between MFW bio-succinate and the (fossil) chemicals and materials sector in terms of conversion, which resulted in both positive and negative influences on the focal TIS. On the one hand, as a result of increasing customer demand and stricter (and more generous) climate mitigation policies, the fossil chemicals and materials sector was interested in increasing the share of bio-based chemicals in their process infrastructure. On the other hand, the MFW bio-succinate TIS's access to conversion processes was restricted by a techno-economic lock-in of physical resources and feedstocks, existing standards, and a general reluctance to take risks. Contrary to expectations, market competition between fossil and bio-based chemicals did not come out as a strong source of influence in this step of the value chain. This might be due to the early stage of development of the focal technology.
- *Frame 4 (green)* shows that there were interdependencies between the focal TIS and the international bio-succinate TIS throughout the value chain. As foreseen, positive influences included (potential) knowledge and technology spill-overs. Contrary to expectations, they also included the first step of the value chain, i.e. the growing activities directed at using waste as a feedstock, which supported legitimation of bio-succinate from food waste. The positive influence also extended to end products and markets, since the international crop-based bio-succinate TIS opened up a niche market for bio-succinate and shared the benefit of public declarations of intent and ambitions to promote markets for bio-based chemicals. However, since the international bio-succinate TIS was a strong competitor for market shares, this downstream interdependency also constituted a negative influence on the focal TIS.
- *Frame 5 (black)* points at the downstream interdependency between the MFW bio-succinate TIS and the (fossil) chemicals and materials sector and (potentially) the bioethanol/ethane TIS in terms of common end products and markets. This resulted in some negative influences, such as competition for market shares (fossil chemicals) and market incentives (bioethanol/ethane) as well as lock-in to some fossil market segments. However, contrary to expectations there were also positive influences. Most notably, market formation for bio-succinate was indirectly supported by public climate mitigation ambitions putting pressure on the fossil chemicals sector, emerging demand from private and public customers for bio-based chemicals and materials, and waste-based bioeconomy solutions (fossil chemicals, bioethanol/ethane). The growing realization that the fossil chemicals and materials sector would not be able to meet the expected increase in demand for chemicals and materials strengthened this further.

To sum up this discussion, the influence of the four context structures on the MFW bio-succinate TIS to a large extent stems from interdependencies throughout the entire value chain. As mentioned above, and similar to other cases described in previous literature

(Hanson, 2018; Mäkitie et al., 2018; Steen and Hansen, 2014), these interdependencies were also the starting point for the formation and subsequent activities of the focal network.

Upstream interdependencies related to the food waste sector and the bioethanol/ethane and biogas TISs had both negative and positive influences, which were related especially to resource availability (feedstock and infrastructure) but also to the wider selection environment (e.g. focus on food waste reduction and norms for using waste for biogas production), which in turn influenced resource accessibility. Thus, in contrast to the study by De Oliveira and Negro (2019), upstream interdependencies do not seem to have been a major source of guidance into the focal TIS but rather steered attention and resources to related TISs.

Downstream interdependencies were more diverse and, as a consequence, the resulting influences were of an ambiguous nature. On the one hand, there were potential synergies to exploit with regard to conversion and production of end products (resource availability), niche market formation (market conditions), and sustainability ambitions and expectations of increasing demand for various bio-chemicals, which bio-succinate could play a part in meeting (wider selection environment). On the other hand, there was competition over market shares and incentives between the focal TIS and most of the related TISs and sectors (market conditions). These downstream interdependencies made the focal TIS extra vulnerable to the tilted selection environment, which as described above benefitted the more institutionalized context structures.

Compared with previous studies, these findings provide some new insights about value chain dependencies and their influence on a focal TIS. First, previous literature has to a large extent focused on structural overlaps as the sources of contextual influences (Bergek et al., 2015; Leitch et al., 2019; Mäkitie et al., 2018). Our study shows that such overlaps do not necessarily result in significant influences on the focal TIS. Indeed, while there were plenty of resource, technology, and actor overlaps, these remained largely unexploited in the studied time period (cf. Leitch et al. (2019) for a similar case). This was to a large extent due to the tilted selection environment, which implied that resources and attention were directed elsewhere. As a consequence, the main upstream (resource) overlap primarily resulted in negative influences on the focal TIS. Institutional overlaps were more important, but as they primarily related to overarching discourses about biochemicals, waste-based solutions and the bioeconomy, rather than to MFW bio-succinate specifically, they also benefitted more institutionalized context structures rather than the focal TIS.

Second, our study illustrates that value chain interdependencies do not necessarily result in positive context influences on a focal TIS but can also be a source of conflict and competition. This contrasts with some of the previous literature, which mainly highlights the potential of exploiting technological and institutional complementarities (Dreher et al., 2016; Haley, 2018; Leitch et al., 2019; Mäkitie et al., 2018). Moreover, although some of these studies indicate that this potential is not always realized due to, for example, technological tensions and misaligned institutions (Haley, 2018; Mäkitie et al., 2018), the MFW bio-succinate case shows that such blocking mechanisms do not only result from highly established, regime-like, context structures but also from other developing (albeit more mature) TISs and can relate to resource availability and accessibility, market conditions, and the wider selection environment. From a policy perspective, it is perhaps most notable how policies that are directed at seemingly unrelated TISs and sectors (such as policies supporting bio-chemicals development by the pulp and paper industry directed at the transport sector) can have a strong negative influence on a focal TIS, due to various direct and indirect interdependencies. This supports findings from some previous studies that innovation system competition can create substantial challenges for actors and policy makers, especially when the competing systems are not equally mature (Magnusson and Berggren, 2018; Sandén and Hillman, 2011).

6. Conclusions and implications

The purpose of this paper was to demonstrate how different technological and sectoral context structures influence the functionality of a focal TIS in an embryonic phase of development (the Swedish MFW bio-succinate TIS), with a particular focus on value chain interdependencies. This purpose was further specified into two research questions: (1) what positive and negative influences do technological and sectoral contexts, respectively, have on the functional pattern of a focal TIS and (2) what up- and downstream interdependencies are the main sources of these influences?

Regarding the first research question, the study shows that all the related TISs and sectors that were included in the analysis had both positive and negative influences on the focal TIS's functional pattern. However, there were no clear patterns of interaction between certain types of context structures and specific functions or modes of influence (positive or negative).

Compared with previous literature, two things stand out. First, the influences from the sectoral context and the international TIS were larger than expected, considering the embryonic nature of the focal TIS. Second, the influence from the main downstream sector (the established sociotechnical configuration) had many positive effects on the focal TIS in terms of, for example, market formation and guidance of the direction of search.

Three main channels through which contextual structures can influence a focal TIS were identified. Context structures influence resource availability and condition resource accessibility. They influence market conditions through demand spill-over as well as competition for market shares and policy support. They also influence the wider selection environment in contradictory ways; they sometimes work together to open up windows of opportunity for a focal TIS but can also tilt the selection environment to its disadvantage.

Regarding the second research question, the study confirms that positive and negative influences to a large extent are the consequence of interdependencies throughout the value chain. Whereas upstream interdependencies especially influenced resource availability/accessibility and some aspects of the wider selection environment, downstream influences were more diverse and ambiguous. There were potential synergies, but also many sources of competition for markets and policy support.

Compared with previous literature, this shows that structural overlaps do not necessarily result in significant contextual influences on a focal TIS. In addition, value chain interdependencies can be a source of conflict rather than complementarity, not only with regard to established sectoral context structures but also to other emerging (but slightly more developed) TISs.

The main implication for research is that a wide perspective on context structures and selection pressures is warranted in future studies, including international aspects, sectoral contexts, and competition also when studying TISs in an early phase of development. In addition, future research projects could explore if the negative contextual influences vary depending on the degree of institutionalization of the context structures in question and how the mode, locus and importance of contextual influences change over the lifecycle of a TIS. However, conducting thorough analyses of contextual influences can easily become a rather demanding task, depending on the number of relevant context structures. We therefore recommend researchers to first do a pre-study to identify the most important structures and then make deeper analyses of these. If predictions in literature are accurate, the importance of context structures will decrease over time; this might imply that context-sensitive analyses of more mature TISs would require less effort.

Finally, while the purpose of this paper was mainly academic, a similar analytical approach can provide important information for industry stakeholders and policymakers. What stands out from the case is how dependent and vulnerable an embryonic TIS can be to exogenous pushes and pulls. Understanding the nature of those forces is therefore imperative to designing appropriate strategies and policies aiming at realizing new technological opportunities and contributing to a transition of unsustainable sociotechnical systems.

CRediT authorship contribution statement

Johanna Ulmanen: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Anna Bergek:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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